# CHAPTER 5

# ENGINE PERFORMANCE AND EFFICIENCY

Your prime concern as an Engineman is to keep the machinery for which you are responsible operating in the most efficient manner possible. From your past experience and training, you know that engine efficiency and performance depend upon much more than just operating the throttle and changing oil at prescribed intervals. The preceding chapters have covered many of the casualties which may occur to reduce the power output of an engine. You have learned how to prevent the occurrence of many of these casualties. As you gain experience and understanding, you will probably have to train other people. The people you will train will frequently come up with many questions about why an engine does or does not perform efficiently. Will you be able to answer their questions?

To understand the various factors that influence engine performance and efficiency, a thorough knowledge of the internal combustion process is necessary. Once the combustion process is understood, it will be much easier for you to appreciate the part played by such factors as engine design, engine operating conditions, fuel characteristics, fuel injection, ignition, pressures and temperatures, and compression ratios. This chapter provides some of the information necessary for a better understanding of the many factors that affect engine performance and efficiency. As an Engineman, you will be able to gain complete understanding of such factors only through continued study and practical experience.

You should know how the power which an engine can develop is limited by such factors as the mean effective pressure, the length of piston stroke, the cylinder bore, and the engine speed. You must also know how these factors are used in determining the power developed by an engine. You must learn how heat losses, efficiency of combustion, volumetric efficiency, and the proper mixing of fuel and air limit the power which a given engine cylinder can develop. You must become familiar with the factors which cause overloading of an engine and unbalance between engine cylinders. You should know the symptoms, causes, and effects of cylinder load unbalance and the steps that are necessary to maintain an equal load on each cylinder.

You must know what is meant by engine efficiency and know how the various types of efficiencies and losses are used in analyzing the internal combustion process. You must also be familiar with those factors which may cause the efficiencies to increase or decrease, and with the ways these variations affect engine performance.

Parts of this chapter may serve as a brief review, but most of the information provided deals with those factors that influence engine performance and efficiency.

## ENGINE PERFORMANCE

In addition to mechanical difficulties, any engine performance may be affected by other causes, such as engine design and operator's performance. A comparison of the principal conditions which influence the performance of internal combustion engines is given in table 5-1. Note that the performance conditions for the two types of engines (diesel and gasoline) are somewhat similar, except for some differences due to factors dealing with fuel and ignition.

### POWER LIMITATIONS

The design of an engine limits the amount of power that an engine can develop. Other limiting

**Table 5-1.—Factors That Influence Engine Performance**

| | Diesel Engines | Gasoline Engines |
|---|---|---|
| 1. Fuel characteristics | X | X |
| 2. Compression ratio | X | X |
| 3. Engine operating conditions | | |
| Combustion chamber design | X | X |
| Valve arrangements | X | X |
| Size of valves | X | X |
| Manifold arrangements | X | X |
| Hot spots (presence/absence) | X | X |
| Location of spark plugs | | X |
| Number of spark plugs | | X |
| 4. Pressure and temperature of air in the engine cylinder at start of compression | X | |
| 5. Pressure/temperature of the charge in the engine cylinder at the start of compression | | X |

factors are the mean effective pressure, the length of stroke, the cylinder bore, and the number of revolutions per minute (piston speed) of the engine. The latter, piston speed, is limited by the frictional heat and by the inertia of the moving parts.

**Mean Effective Pressure**

The mean effective pressure (MEP) is the average pressure exerted on the piston during each power stroke, and is determined from a formula or by means of a planimeter. There are two kinds of mep: indicated mean effective pressure (imep), which is developed in the cylinder and can be measured; and brake mean effective pressure (bmep), which is computed from the brake horsepower (bhp) delivered by the engine.

**Length of Stroke**

The distance a piston travels between top and bottom dead centers (TDC, BDC) is known as the length of stroke. This distance is one of the factors that determines the piston speed. In some modern diesel engines, piston speeds may reach about 1600 feet per minute (fpm).

**Cylinder Bore**

Bore is used to identify the diameter of the cylinder. The cylinder bore must be known in order to compute the area of the piston crown upon which the pressure acts to create the driving force. This pressure is calculated and expressed for an area of one square inch as pounds per square inch (psi).

The ratio of length of stroke to cylinder bore is fixed in engine design; in most slow speed engines, the stroke is greater than the bore.

### Revolutions Per Minute

Revolutions per minute (rpm) is the speed at which the crankshaft rotates. Since the piston is connected to the shaft, the rpm, along with the length of the stroke, determine piston speed. Since, during each revolution, the piston completes one up-stroke and one down-stroke, piston speed is obtained by multiplying the rpm by twice the length of the stroke. This speed is usually expressed in feet per minute (fpm). If the stroke is 10.5 inches (or 10.5/12 of a foot), and the speed of rotation is 720 rpm, the piston speed is computed as follows:

$$720 \times 2 \times \frac{10.5}{12} = 1260 \text{ fpm}$$

## HORSEPOWER COMPUTATION

The power developed by an engine depends upon the type of engine as well as the speed of the engine. A cylinder of a single-acting, 4-stroke cycle engine will produce one power stroke for every two crankshaft revolutions, while a single-acting, 2-stroke cycle engine produces one power stroke for each revolution.

### Indicated Horsepower

The power developed within a cylinder can be calculated by measuring the imep and the engine speed. (The rpm of the engine is converted to the number of power strokes per minute.) With the bore and stroke known (available in engine manufacturers' technical manuals), the horsepower (hp) can be computed. This power is called indicated horsepower (ihp) because it is obtained from the pressure measured with an engine indicator. Power loss due to friction is not considered in computing ihp.

Using the factors which influence the engine's capacity to develop power, the general or standard formula for calculating ihp is as follows:

$$\text{ihp} = \frac{P \times L \times A \times N}{33{,}000}$$

where

P = Mean indicated pressure, in psi

L = Length of stroke, in feet

A = Effective area of the piston, in square inches

N = Number of power strokes per minute

33,000 = Unit of power (one horsepower), or footpounds per minute.

To illustrate the use of this formula, assume that a 12-cylinder, 2-stroke cycle, single-acting engine has a bore of 8.5 inches and a stroke of 10 inches. Its rated speed is 744 rpm. With the engine running at full load and speed, the imep is measured and found to be 105 psi. What is the ihp developed by the engine?

In this case

$$P = 105; \quad L = \frac{10}{12};$$

$$A = 3.1416\left(\frac{8.5}{2}\right)^2; \quad N = 744$$

Substituting these amounts in the formula, you have

$$\text{ihp} = \frac{105 \times \frac{10}{12} \times 3.1416\left(\frac{8.5}{2}\right)^2 \times 744}{33{,}000} = 111.9$$

This amount represents the horsepower developed in only one cylinder; since there are 12 cylinders in this engine, total horsepower for the engine will equal 12 times 111.9, or approximately 1343.

### Brake Horsepower

Brake horsepower (bhp), sometimes called shaft horsepower, is the amount of power available for useful work. Bhp is less than ihp because of the various power losses which occur during engine operation.

To determine the brake or shaft horsepower that is delivered as useful work by an engine, the sum total of all mechanical losses must be deducted from the total ihp.

## CYLINDER PERFORMANCE LIMITATIONS

The factors which limit the power that a given cylinder can develop are the piston speed and the mep. The piston speed, as stated before, is limited by the inertia forces set up by the moving parts and by frictional heat. In the case of the mep, the limiting factors are as follows:

1. Heat losses and efficiency of combustion.
2. Volumetric efficiency (the amount of air charged into the cylinder and the degree of scavenging).
3. Mixing of the fuel and air.

The limiting meps, both bmep and imep, are prescribed by the manufacturer or NAVSEA. They should never be exceeded. In a direct-drive ship, the meps developed are determined by the rpm of the power shaft. In electric-drive ships, the horsepower and bmep are determined by a computation based on readings from electrical instruments and from generator efficiency.

## CYLINDER LOAD BALANCE

In order to ensure a balanced, smooth-operating engine, the general mechanical condition of the engine must be properly maintained so that the power output of the individual cylinders is within the prescribed limits at all loads and speeds. In order to have a balanced load on the engine, each cylinder must produce its share of the total power developed. If the engine is developing its rated full power, or nearly so, and one cylinder or more is producing less than its share, the remainder of the cylinders will become overloaded.

Using the rated speed and bhp, it is possible to determine for each INDIVIDUAL CYLINDER a rated bmep which may not be exceeded without overloading the cylinder. If the ENGINE rpm drops below the rated speed, then the cylinder bmep generally drops to a lower value. The bmep should never exceed the normal mep at lower engine speed. Usually, it should be somewhat lower if the engine speed is decreased.

Some engine manufacturers design the fuel systems so that it is impossible to exceed the rated bmep. This is done by installing a positive stop to limit the maximum throttle or fuel control. This positive stop regulates the maximum amount of fuel that can enter the cylinder and limits the maximum load of the cylinder.

In order to meet emergency situations, engines used by the Navy are generally rated lower than those designed for industrial use. The economical speed for most of the Navy's diesel engines is approximately 90% of the rated speed. For such speed, the best load conditions have been found to be from 70% to 80% of the rated load or output. When an engine is operated at an 80-90 combination (80% of rated load at 90% rated speed) the parts last longer and the engine remains cleaner and in better operating condition.

Diesel engines do not operate well at exceedingly low bmep such as that occurring at idling speeds. You are well aware that idling an engine tends to gum up parts associated with the combustion spaces. Operating an engine at idling speeds for long periods will result in the necessity for cleaning and overhauling the engine much sooner than when operating at 50 to 100% of load.

### Symptoms of Unbalance

Evidence of an unbalanced condition between the cylinders of an engine may be indicated by the following symptoms:

1. Black exhaust smoke. When this occurs, it is not always possible to determine immediately whether the entire engine or just one of the cylinders is overloaded. To determine which cylinder is overloaded, you must open the

indicator cock on each individual cylinder and check the color of the exhaust.

2. High exhaust temperatures. If the temperatures of exhaust gases from individual cylinders become higher than normal, it is an indication of an overload within the cylinder. If the temperature of the gases in the exhaust header becomes higher than usual, it is an indication that all cylinders are probably overloaded. Frequent checks on the pyrometer will indicate whether each cylinder is firing properly and carrying its share of the load. Any sudden change in the exhaust temperature of any cylinder should be investigated immediately. The difference in exhaust temperatures between any two cylinders should not exceed the limits prescribed in the engine manufacturer's technical manual.

3. High lubricating oil and cooling water temperatures. If the temperature gages for these systems show an abnormal rise in temperature, an overloaded condition may exist. The causes of the abnormal temperature in these systems should be determined and corrected immediately if engine efficiency is to be maintained.

4. Excessive heat. In general, excessive heat in any part of the engine may indicate overloading. An overheated bearing may be the result of an overloaded cylinder; or an abnormally hot crankcase may be the result of overloading the engine as a whole.

5. Excessive vibration or unusual sound. If all cylinders are not developing an equal amount of power, the forces exerted by individual pistons will be unequal. When this occurs, the unequal forces cause an uneven turning movement to be exerted on the crankshaft, and vibrations are set up. Through experience, you will learn to tell by the vibrations and sound of an engine when a poor distribution of load exists. You should use every opportunity to observe and listen to engines running under all conditions of loading and performance.

**Causes of Unbalance**

An engine must be kept in excellent mechanical condition to prevent unbalance. A leaky valve or fuel injector, leaky compression rings, or any other mechanical difficulties will make it impossible for you to balance the load unless you secure the engine and dismantle at least a part of it.

To obtain equal load distribution between individual cylinders, the clearances, tolerances, and the general condition of all parts that affect the cycle must be maintained so that very little, if any, variation exists between individual cylinders. Unbalance will occur unless the following conditions are as nearly alike as possible for all cylinders:

1. Compression pressures
2. Fuel injection timing
3. Quantity and quality of fuel injected
4. Firing pressures
5. Valve timing and lift

When unbalance occurs, correction usually involves repair, replacement, or adjustment of the affected part or system. Before any adjustments are made to eliminate unbalance, it must be determined beyond any doubt that the engine is in proper mechanical condition. When an engine is in good mechanical condition, few adjustments will be required. However, after an overhaul in which piston rings or cylinder liners have been renewed, considerable adjustment may be necessary. Until the rings become properly seated, some lubricating oil will leak past the rings into the combustion space. This excess oil will burn in the cylinder, giving an incorrect indication of fuel oil combustion. If the fuel pump is set for normal compression, and the rings have not seated properly, the engine will become overloaded. As the compression rises to normal pressures, there will be an increase in the power developed, as well as in the pressure and temperature under which the combustion takes place. Therefore, when an overhaul has been completed, the engine instruments must be carefully watched until the rings are seated, and all necessary adjustments are made. Frequent compression tests will serve as a helpful aid in making the necessary adjustments. Unless an engine is so equipped that compression can be readily varied, the engine should be operated under light load until the rings are properly seated.

### Effect of Unbalance

From the preceding discussion, it can be readily seen that, in general, the result of unbalance will be overheating of the engine. The clearances established by the engine designer allow for sufficient expansion of the moving parts when the engine is operating at the designed temperatures, but an engine operating at temperatures in excess of those for which it was designed is subject to many casualties. Excessive expansion soon leads to seizure and burning of the engine parts. Should the temperatures in the crankcase rise above the flash point of the lubricating oil vapors, an explosion may result. High temperature may destroy the oil film between adjacent parts, and the resulting increased friction will further increase the temperature.

Since power is directly proportional to the mep developed in a cylinder, any increase in mep will cause a corresponding increase in power. If the meps in the individual cylinders vary, power will not be evenly distributed among the cylinders.

The quality of combustion obtained depends upon the heat content of the fuel. The amount of heat available for power depends upon temperature. Temperature varies directly as pressure; therefore a decrease in pressure will result in a decrease in temperature, and in poor combustion. Poor combustion will cause lowered thermal efficiency and reduced engine output.

Cylinder load balance is essential if the desired efficiency and performance of an engine is to be obtained. To avoid the harmful effects of overloading and unbalancing of load, the load on an engine should be properly distributed among the working cylinders; and no cylinder, or the engine itself, should ever be overloaded.

In general, load balance in an engine can be maintained if the following procedures are observed:

1. Maintain the engine in proper mechanical condition.
2. Adjust the fuel system according to the manufacturer's instructions.
3. Operate the engine within the temperature limits specified in appropriate instructions.
4. Keep cylinder temperatures and pressures as evenly distributed as possible.
5. Train yourself to recognize the symptoms of serious engine conditions.

## ENGINE EFFICIENCY

Engine efficiency is the amount of power developed as compared to the energy input which is measured by the heating value of the fuel consumed. The term "efficiency" is used to designate the relationship between the result obtained and the effort expended to produce the result.

The term "compression ratio" is frequently used in connection with engine performance. From your study of the principles of internal combustion, you will recall that compression ratio is the ratio of the volume of air above the piston, when the piston is at the BDC position, to the volume of air above the piston when the piston is at the TDC position.

## EFFICIENCIES

The principal efficiencies which must be considered in the internal combustion process are cycle, thermal, mechanical, and volumetric.

### Cycle Efficiency

The efficiency of any cycle is equal to the output divided by the input. The efficiency of the diesel cycle is considerably higher than the Otto or constant volume cycle because of higher compression ratio and because combustion starts at a higher temperature. In other words, the heat input in a diesel engine is at a higher average temperature. Theoretically, a gasoline engine using the Otto cycle would be more efficient than the diesel engine if equivalent compression ratios could be used. However, engines operating on the Otto cycle cannot use a compression ratio comparable to that of diesel engines because fuel and air are drawn together into the cylinder and compressed. If comparable compression ratios were used, the fuel would fire or detonate before the piston reached the correct firing position.

Since temperature and amount of heat content which is available for power are proportional to each other, the cycle efficiency is actually computed by measuring the temperature. The specific heat of the mixture in the cylinder is either known or assumed, and when combined with the temperature, the heat can be calculated at any instant.

**Thermal Efficiency**

Thermal efficiency is the measure of the efficiency and completeness of combustion of the fuel, or, more specifically, the ratio of the output or work done by the working substance in the cylinder in a given time to the input or heat energy of the fuel supplied during the same time. Two kinds of thermal efficiency are generally considered for an engine: indicated thermal efficiency and overall thermal efficiency.

Since the work done by the gases in the cylinder is called indicated work, the thermal efficiency determined by its use is often called INDICATED THERMAL EFFICIENCY (ite). If all the potential heat in the fuel could be delivered as work, the thermal efficiency would be 100%. Because of the various losses, however, this percent is not possible in actual installations.

If the amount of fuel injected is known, the total heat content of the injected fuel can be determined from the heating value, or Btu per pound, of the fuel; and the thermal efficiencies for the engine can then be calculated. From the mechanical equivalent of heat (778 foot-pounds equal 1 Btu and 2545 Btu equal 1 hp-hr), the number of foot-pounds of work contained in the fuel can be computed. If the amount of fuel injected is measured over a period of time, the rate at which the heat is put into the engine can be converted into potential power. Then, if the ihp developed by the engine is calculated, as previously explained, the indicated thermal efficiency can be computed by the following expression:

$$\text{ite} = \frac{\text{hp} \times 2545 \text{ Btu per hr per hp}}{\text{Rate of heat input of fuel in Btu per hr}} \times 100$$

For example, assume that the same engine used as an example in computing ihp consumes 360 pounds (approximately 50 gallons) of fuel per hour, and that the fuel has a value of 19,200 Btu per pound. What is the ite of the engine?

The work done per hour when 1343 ihp are developed is 1343 × 2545 or 3,417,935 Btu. The heat input for the same time is 360 × 19,200 or 6,912,000 Btu. Then, by the above expression, the indicated thermal efficiency is as follows:

$$\text{ite} = \frac{1343 \times 2545}{360 \times 19{,}200} \times 100$$

$$= \frac{3{,}417{,}935}{6{,}912{,}000} \times 100 = 49.4\%$$

The other type of thermal efficiency—OVERALL THERMAL EFFICIENCY—considered for an engine is a ratio similar to ite, except that the useful or shaft work (bhp) is used. Therefore, overall efficiency (often called brake thermal efficiency) is computed by the following expression:

$$\text{Overall thermal efficiency} = \frac{\text{bhp}}{\text{Heat input of fuel}} \times 100$$

Converting these factors into the same units (Btu), the expression is written as power output in Btu divided by fuel input in Btu.

For example, if the engine used in the preceding problem delivers 900 bhp (determined by the manufacturer) what is the overall thermal efficiency of the engine?

1 hp-hr = 2545 Btu

900 bhp × 2545 Btu per hp-hr =

2,290,500 Btu output per hr

Substituting factors already known, overall thermal efficiency is computed as follows:

$$\text{Overall thermal efficiency} = \frac{2{,}290{,}500}{6{,}912{,}000} = 0.331, \text{ or } 33.1\%$$

Compression ratio influences the thermal efficiency of an engine. Theoretically, the thermal efficiency increases as the compression ratio is increased. The minimum value of a diesel engine compression ratio is determined by the compression required for starting; and this compression is, to a large extent, dependent on the type of fuel used. The maximum value of the compression ratio is not limited by the fuel used, but is limited by the strength of the engine parts and the allowable engine weight per bhp output.

**Mechanical Efficiency**

This is the rating that shows how much of the power developed by the expansion of the gases in the cylinder is actually delivered as useful power. The factor which has the greatest effect on mechanical efficiency is friction within the engine. The friction between moving parts in an engine remains practically constant throughout the engine's speed range. Therefore, the mechanical efficiency of an engine will be highest when the engine is running at the speed at which maximum bhp is developed. Since power output is bhp, and the maximum horsepower available is ihp, then

$$\text{Mechanical efficiency} = \frac{\text{bhp}}{\text{ihp}} \times 100$$

During the transmission of ihp through the piston and connecting rod to the crankshaft, the mechanical losses which occur may be due to friction, or they may be due to power absorbed. Friction losses occur because of friction in the various bearings, between piston and piston rings, and between piston rings and the cylinder walls. Power is absorbed by valve and injection mechanisms, and by various auxiliaries, such as the lubricating oil and water circulating pumps and the scavenge and supercharge blowers. As a result, the power delivered to the crankshaft and available for doing useful work (bhp) is less than indicated power.

The mechanical losses which affect the efficiency of an engine may be called frictional horsepower (fhp) or the difference between ihp and bhp. The fhp of the engine used in the preceding examples, then, would be 1343 (ihp) – 900 (bhp) = 443 fhp, or 33% of the ihp developed in the cylinders. Then, using the expression for mechanical efficiency, the percentage of power available at the shaft is computed as follows:

$$\text{Mechanical efficiency} = \frac{900}{1343} = 0.67, \text{ or } 67\%$$

When an engine is operating under part load, it has a lower mechanical efficiency than when operating at full load. The explanation for this is that most mechanical losses are almost independent of the load, and therefore, when load decreases, ihp decreases relatively less than bhp. Mechanical efficiency becomes zero when an engine operates at *no* load because then bhp = 0, but ihp is not zero. In fact, if bhp is zero and the expression for fhp is used, ihp is equal to fhp.

To show how mechanical efficiency is lower at part load, assume the engine used in preceding examples is operating at three-fourths load. Brake horsepower at three-fourths load is 900 × 0.75 or 675. Assuming that fhp does not change with load, fhp = 443. The ihp is, by expression, the sum of bhp and fhp.

$$\text{ihp} = 675 + 443 = 1118$$

Mechanical efficiency = 675/1118 = 0.60, or 60%; this is appreciably lower than the 67% indicated for the engine at full load.

Bmep is a useful concept when dealing with mechanical efficiency. Bmep can be obtained if the standard expression for computing horsepower (ihp) is applied to bhp instead of ihp and the mean pressure (p) is designated as bmep.

$$\text{bhp} = \frac{(\text{bmep}) \times L \times A \times N}{33{,}000}$$

or

$$\text{bmep} = \frac{33{,}000 \times \text{bhp}}{L \times A \times N}$$

From the relations between bmep, bhp, ihp, and mechanical efficiency, by designating indicated mean effective pressure by imep in the expression, one can also show:

bmep = imep × mechanical efficiency

To illustrate this, the bmep for the engine in preceding examples at full load and three-fourths load is computed as follows:

$$\text{bmep} = \frac{33{,}000 \times \frac{\text{bhp}}{12}}{L \times A \times N} = \frac{33{,}000 \times \frac{900}{12}}{\frac{10}{12} \times 56.14 \times 744}$$

$$= 70 \text{ psi}$$

or

$$\text{bmep} = \text{imep} \times \text{mechanical efficiency}$$

$$= 105 \times 67, \text{ or } 70 \text{ psi}$$

Bmep gives an indication of the load an engine carries, and what the output is for piston displacement. As the bmep for an engine increases, the engine develops greater horsepower per pound of weight. For a given engine, bmep changes in direct proportion with the load.

### Volumetric Efficiency

The volumetric efficiency of a 4-stroke engine is the relationship between the quantity of intake air and the piston displacement. In other words, volumetric efficiency is the ratio between the charge that actually enters the cylinder and the amount that could enter under ideal conditions. Piston displacement is used since it is difficult to measure the amount of charge that would enter the cylinder under ideal conditions. An engine would have 100% volumetric efficiency if, at atmospheric pressure and normal temperature, an amount of air exactly equal to piston displacement could be drawn into the cylinder. This is not possible, except by supercharging, because the passages through which the air must flow offer a resistance, the force pushing the air into the cylinder is only atmospheric, and the air absorbs heat during the process. Therefore, volumetric efficiency is determined by measuring (with an orifice or venturi type meter) the amount of air taken in by the engine, converting the amount to volume, and comparing this volume to the piston displacement.

$$\text{Volumetric efficiency} =$$

$$\frac{\text{Volume of air admitted to cylinder}}{\text{Volume of air equal to piston displacement}} \times 100$$

The concept of volumetric efficiency does not apply to 2-stroke cycle engines. Instead, the term “scavenge efficiency” is used. Scavenge efficiency shows how thoroughly the burned gases are removed and the cylinder filled with fresh air. As in the case of a 4-stroke cycle engine, it is desirable that the air supply be sufficiently cool. Scavenge efficiency depends largely upon the arrangement of the exhaust, scavenge air ports, and valves.

## ENGINE LOSSES

As the heat content of a fuel is transformed into useful work, during the combustion process, many different losses take place. These losses can be divided into two general classifications: thermodynamic and mechanical. The net useful work delivered by an engine is the result obtained by deducting the total losses from the heat energy input.

### Thermodynamic Losses

Losses of this nature are a result of the following: loss to the cooling and lubricating systems; loss to the surrounding air; loss to the exhaust; and loss due to imperfect combustion.

Heat energy losses from both the cooling water systems and the lubricating oil system are always present. Some heat is conducted through the engine parts and radiated to the atmosphere or picked up by the surrounding air by convection. The effect of these losses varies according to the part of the cycle in which they occur. The heat of the jacket cooling water cannot be taken as a true measure of heat losses, since all this heat is not absorbed by the water. Some heat is lost to the jackets during the compression, combustion, and expansion phases of the cycle; some is lost (to the atmosphere) during the exhaust stroke; and some is absorbed by the walls of the exhaust passages.

Heat losses to the atmosphere through the exhaust are unavoidable. This is because the engine cylinder must be cleared of the hot exhaust gases before the next air intake charge can be made. The heat lost to the exhaust is determined by the temperature within the cylinder when exhaust begins. The amount of fuel injected and the weight of air compressed within the cylinder are the controlling factors. Improper timing of the exhaust valves, whether too early or too late, will result in increased heat losses. If too early, the valve releases the pressure in the cylinder before all the available work is obtained; if too late, the necessary amount of air for complete combustion of the next charge cannot be realized, although a small amount of additional work may be obtained. Proper timing and seating of the valves is essential in order to maintain heat loss to the exhaust at a minimum.

Heat losses due to imperfect or incomplete combustion have a serious effect on the power that can be developed in the cylinder. Because of the short interval of time necessary for the cycle in modern engines, complete combustion is not possible; but heat losses can be kept to a minimum if the engine is kept in proper adjustment. It is often possible to detect incomplete combustion by watching for abnormal exhaust temperatures and changes in the exhaust color, and by being alert for unusual noises in the engine.

**Mechanical Losses**

There are several kinds of mechanical losses, but all are not present in every engine. The mechanical or friction losses of an engine include bearing friction; piston and piston ring friction; pumping losses caused by operation of water pumps, lubricating pumps, and scavenging air blowers; power required to operate valves; etc. Friction losses cannot be eliminated, but they can be kept to a minimum by maintaining the engine in its best mechanical condition. Bearings, pistons, and piston rings should be properly installed and fitted, shafts must be in alignment, and lubricating and cooling systems should be at their highest operating efficiency.